Temporal Pattern Analysis of Rainstorm Events for Supporting Rainfall Design in a Tropical City

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Abstract. Synthetic rainfall distributions of the design storm have been commonly used for the hydrological design of urban stormwater infrastructures in many regions of the world. However, there are still limited studies in a tropical city dealing with design storm hyetographs for flood estimation even though rainfall intensity/depth-duration-frequency (IDF/DDF) relationships have been derived to estimate rainfall depths for a specific rainfall duration and return period. This study presents a storm-event based rainfall analysis method to determine a representative quartile of the design storm in which, both inter-event time definition (IETD) and depth/duration/intensity thresholds are considered. Similar to Huff's method, 5-min rainfall data during three years at two rain gauge stations in Singapore were used to obtain the percentage frequency of the four types of quartile storms depending on the location where the heaviest rainfall occurred in each storm duration. It was found that the proposed approach could give the shape and magnitude of the design storm hyetograph from the location of peak rainfall corresponding to the largest portion of quartile storms. As a result, the second quartile design storm was suggested to be applied for flood estimation in order to better address the temporal characteristic of actual rainstorm events in the study area. It offers an alternative way of describing the temporal distribution of rainfall within a design storm period, which is helpful in improving the design of urban stormwater infrastructures in a tropical region.

Keywords: Design storm · Temporal distribution · Peak rainfall
Huff's method · Singapore

1 Introduction

In engineering practice, the design rainfalls have been used to estimate flood quantiles at a catchment scale (Varga et al. 2009), which is especially useful for the hydrologic design of urban stormwater infrastructures such as culverts and drainage systems. The magnitude of precipitation extremes corresponding to various frequencies and durations was firstly determined from the rainfall intensity-duration-frequency (IDF) or depth-duration-frequency (DDF) relationships (Liew 2012). The different shapes of

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synthetic hyetographs were then considered along with design storm's temporal patterns (Wenzel 2013). One particular approach to the development of synthetic hyetographs is the Huff's method (Huff 1967). It separates rainstorm events into four groups, followed by the location where the maximum intensity occurred during each storm duration. The method of characterizing dimensionless storm mass curves is provided for a given elapsed time, which describes a probabilistic representation of cumulative rainfall depths corresponding to the considered storm duration (Liew 2012).

For tropical regions, some studies were reported in temporal distribution of rainfall. Koon (1969) analyzed temporal patterns of 377 rainstorm events at five climate stations located in Singapore and suggested the use of an average temporal pattern for flood estimation in designing drainage networks, obtained from the dimensionless mass curve. Tan and Sia (1997) developed an algorithm for simulating tropical rainfall using a Markov chain. In the past years, the storm-event based approaches were applied to properly reflect rainfall characteristics of actual rainstorm events (Yoo et al. 2016). These approaches tend to separate individual rainstorm events from rainfall time series over the entire record period and help mitigate the limitations of the rainfall quantities corresponding to the pre-selected time intervals. More detailed information about the definition of rainstorm events is given in Jun et al. (2017). Overall, there is a lack of study that focuses on using storm-event based concept to study temporal pattern of rainstorm events in the tropical region like Singapore.

The objective of this study is then to preliminarily tackle such a gap by proposing a storm-event based approach for determining a representative quartile of the design storm for the benefit of supporting rainfall design. Individual rainstorm events are retrieved from choosing proper values for the inter-event time definition (IETD) and depth/duration/intensity thresholds. IETD is defined as the minimum no-rain periods between consecutive rainstorm events (Jun et al. 2017). Followed by the location of the heaviest rainfall during each storm duration, the retrieved events are divided into four groups. The proposed approach is applied to 5-min rainfall data at two rain gauge stations in Singapore. The methodology is presented first, followed by application results and discussion, and conclusions.

2 Methodology

The overall methodological framework of determining the representative quartile of the design storm in a tropical city is summarized in Fig. 1. Each rainstorm event needs to be defined for investigating general characteristics of the temporal variation in its rainfall intensity. From the observed rainfall time series (Step 1), we only consider rainfall data with intensity larger than 0.3 mm per 5 min and duration longer than 5 min to retrieve proper rainstorm events (Step 2), which can reduce the error in determining quartiles of each rainstorm events followed by the location where the maximum intensity occurred within a storm duration. The IETD of 20 min is applied to retrieve individual rainstorm events (Step 3). Among them, a sequence of rainstorm events with total storm depths larger than 3 mm is determined firstly (Step 4) and then the individual rainstorm events of interest are obtained finally, which have storm durations longer than 30 min (Step 5). Based on the Huff's method, they are divided

into four groups depending on the location where the peak rainfall intensity occurred, i.e., during the first, second, third or fourth quarter of the storm duration (Step 6). It is noted that each threshold value needs to be determined from regional characteristics including precipitation extremes.

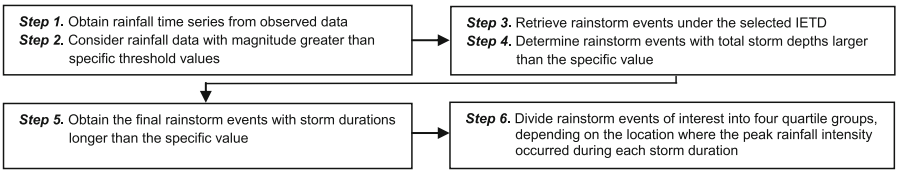

Fig. 1. Flow chart of a storm-event based approach for determining the representative quartile of the design storm in a tropical city

3 Application Results and Discussion

3.1 Data

Singapore is located in Southeast Asia with average annual rainfall depths around 2,400 mm (PUB 2011). Even though the rainfall IDF or DDF relationships have been developed to estimate design rainfalls corresponding to a specific rainfall duration and return period, there are still limited studies dealing with design storm hyetographs for flood estimation in Singapore. This study analyzed 5-min rainfall series during three years (July 2010 - June 2013) and retrieved a sequence of rainstorm events from rainfall time series at two rain gauge stations; one is located at the middle part of the island, namely MacRitchie Reservoir (Station #1) and the other is on the eastern side, namely Changi Airport (Station #2). The total number of retrieved rainstorm events was 308 and 248, respectively. The locations of the considered rain gauge stations and the statistical characteristics of retrieved rainstorm events are summarized in Fig. 2. It is noted that the values of mean and standard deviation are close to each other even though two rain gauge stations are located relatively far apart. Especially, the mean value of storm durations is about one hour, which potentially reflecting the importance of temporal patterns in storms corresponding to relatively short durations for designing urban stormwater infrastructures in the tropical region like Singapore.

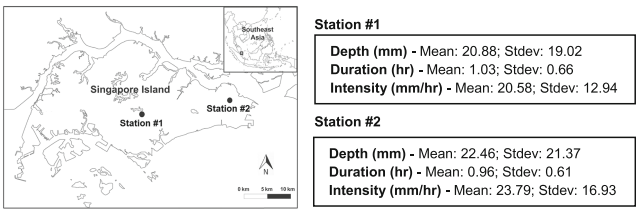

Fig. 2. The locations of two rain gauge stations and the statistical characteristics of retrieved rainstorm events

3.2 Temporal Pattern of Rainstorm Events in Singapore

The retrieved rainstorm events were divided into four groups, depending on the location where the heaviest rainfall occurred in each storm duration (Fig. 3).

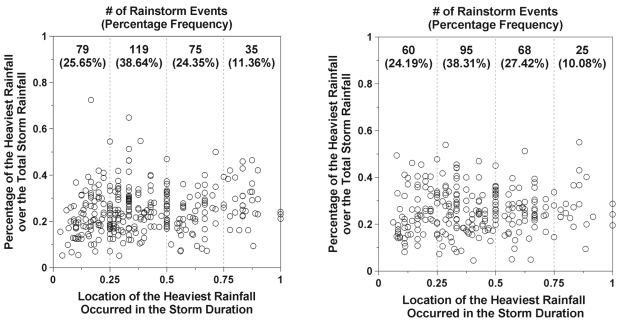

Fig. 3. The scatter plot for identifying a representative temporal pattern of rainstorm events in Singapore with the number of rainstorm events corresponding to each quantile storm and their percentage frequencies: (a) Station #1; (b) Station #2

From the percentage frequency of the four types of quartile storms, it is noted that the second quartile storms correspond to the largest portion of rainstorm events, i.e. 38.64% for Station #1 and 38.31% for Station #2. It implies that the second quartile storms could represent the main temporal characteristics of actual rainstorm events in Singapore. The proposed approach helps figure out the shape of design storm hyetographs followed by the location of the heaviest rainfall in a storm duration even though there are still limitations such as the selection of IETD and depth/duration/intensity thresholds, the absolute number of the considered rain gauge stations, types of quartiles and time interval of observation data. We leave it to further studies.

4 Conclusions

This study proposed a storm-event based approach for determining a representative quartile of the design storm, focusing on the location of the heaviest rainfall in a storm duration. Both inter-event time definition (IETD) and depth/duration/intensity thresholds were considered to retrieve rainstorm events of interest from rainfall time series of observed data. The retrieved rainstorm events were divided into four groups followed by the location where the heaviest rainfall occurred during the first, second, third or fourth quarter of the storm duration. This proposed approach was applied to analyze storm characteristics of 5-min rainfall data during three years at two rain gauge stations in Singapore. The study demonstrated that the percentage frequency of the second quartile storms was the highest among the considered four types of quartile storms, which represent temporal characteristics of actual rainstorm events in Singapore. It depends on the selected values of the IETD and thresholds and thus the proposed

approach needs to consider regional characteristics including precipitation extremes. The study results could be applied to develop different shapes of synthetic hyetographs in a tropic city, which is important for flash flood estimation, hydraulic structure design and risk/uncertainty analysis.

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